Acquiring expertise in precision sport - What can we learn from an elite snooker player?

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Abstract
Snooker can be an attractive life-long physical activity, given its popularity across all age groups in Asia and Europe. However, scientific research on the cueing movement is limited. This case study presented the biomechanical profiles of the cueing movement in an elite male snooker player (age 37 years old, height 173 cm, body mass 70 kg). Kinematics of the upper limb and cue stick were examined in five selected snooker tasks (warm-up, stun, top spin, back spin, and stop shots) using the Vicon motion capture system. Ground reaction forces and centre of pressure characteristics were recorded using two Kistler force platforms. Results showed that the cueing movement was contributed primarily by elbow flexion/extension and much less wrist flexion/extension. The high degree of cue stick position overlap between the practice swing and final stroke-indicated high level of cueing precision.-Weight transfer between feet revealed a slight lean towards the left foot throughout the final stroke, confirming that the elite player was able to maintain high stance stability when executing the cueing movement. Results presented in the present study can serve as a reference for practitioners and scientists to detect error, enhance training, and improve performance in snooker. For practical applications, snooker players are advised to stabilise their shoulder during the cueing movement and deliver the cue stick primarily via elbow movements.

Keywords: cue tip, speed, position, kinematic, ground reaction force, centre of pressure

Introduction

Staying physically active is important for good health and well-being throughout one's lifespan (Ozemek et al., 2019; Reimers et al., 2012). One key factor for enhancing exercise adherence is to select an appropriate form of physical activity that the individuals would enjoy (Lewis et al., 2016). Precision sports such as snooker can be an attractive life-long activity for many, given that it engages social interaction with other players and is less physically demanding compared with other forms of exercises such as running and ball games.

Snooker is one discipline of cue sports played on a rectangular table with the playing surface size of 356.9 cm by 177.8 cm (11 feet 8.5 inches by 5 feet 10 inches). There are 22 balls in total, comprising 1 cue (white) ball, 15 red balls, and 6 coloured balls (1 yellow, 1 green, 1 brown, 1 blue, 1 pink, and 1 black). A player pots one red ball and then one coloured ball, accumulating scores to win the game. Snooker is popular across a wide range of age groups from youth to older adults, particularly in Asia and Europe (Harris, 2020). An investigation into the professional snooker tournaments took place between 1968 and 2020 (over 50 years) (O'Brien, 2021) found that 18 players were still active by the year of 2020 who had a sports career life lasting more than 30 years. This suggests that snooker can be a life-long physical activity for players of all ages, both recreationally and competitively.

Experiencing success and perceiving personal growth in a sport can motivate one to continue participation (Hallmann & Harms, 2012). Thus, it is of interest to investigate how expert snooker players acquire their skills in achieving high degree of precision and accuracy. In snooker, there is primarily only one kind of cueing movement which consisted of several practice swings and a final stroke. Across the games, the cueing movement is varied in speeds and amounts of force and spins applied in order to hit the object balls at various distances and to strategically place the cue ball in a desirable position for the next shot. Previous studies have investigated the physics of the ball movements on the table, such as ball-on-ball collision (White, 2017) and mathematical explanation of the slice shots (Jankunas & Zare, 2014). However, biomechanics investigation of the human body was rather limited. Only a few studies have reported the kinematic data of snooker shots such as upper limb joint angles and cue stick angles (Song et al., 2018; Zhou et al., 2018). Snooker players often perform a few practice swings before the final stroke to help aim and correct the length of the back swing. No previous studies have compared the biomechanics of the cueing movement between the practice swings and the final stroke. In the current literature, there are no available kinetic data, namely ground reaction forces (GRF) and centre of pressure (COP) under the feet, of the cueing movement in snooker or other forms of cue sports. Since snooker is relatively 'static' and requires high stance stability for the cue stick delivery, GRF and COP data may reveal insightful information on dynamic stability as previously demonstrated in other 'static' sports such as golf and archery (Ball & Best, 2007a, 2007b; Simsek et al., 2019).

The present case study aimed to comprehensively profile the biomechanical characteristics of the cueing movements of one professional snooker player. The kinematics and kinetics of both practice swings and the final stroke would be quantified. The cueing techniques employed by the elite player could serve as a reference for other players, guiding them towards successful performance.

Methods

<u>*Participant*</u>

This study was approved by the [*removed for blind review*] Research Ethics Committee (Protocol number: [*removed for blind review*]). Biomechanical analyses were performed on one professional snooker player (male, 37 years old, height 173 cm, body mass 70 kg) who competed internationally representing xxx [*removed for blind review*].

<u>*Protocols*</u>

An overview of the data collection and data analysis procedures are shown in Figure 1. Five types of shots were selected for analysis, including 1) warm-up shots, 2) stun shots, 3) top spin shots, 4) back spin shots, and 5) stop shots. The participant performed 3 trials in each type of shots. Across all tasks, the cue ball was placed on the right side of the player at the 'yellow spot' where the yellow ball is placed in the beginning of each snooker game (Figure 2). For tasks involving long shots (back spin and stop tests), an object ball (black) was positioned at the intersection of the middle line and the line crossing the cue ball and the corner pocket. An object ball was set at the midway between the cue ball and the position of the black ball for the short shots (warm-up, stun, and top spin shots). The detailed procedures are presented in Table 1.

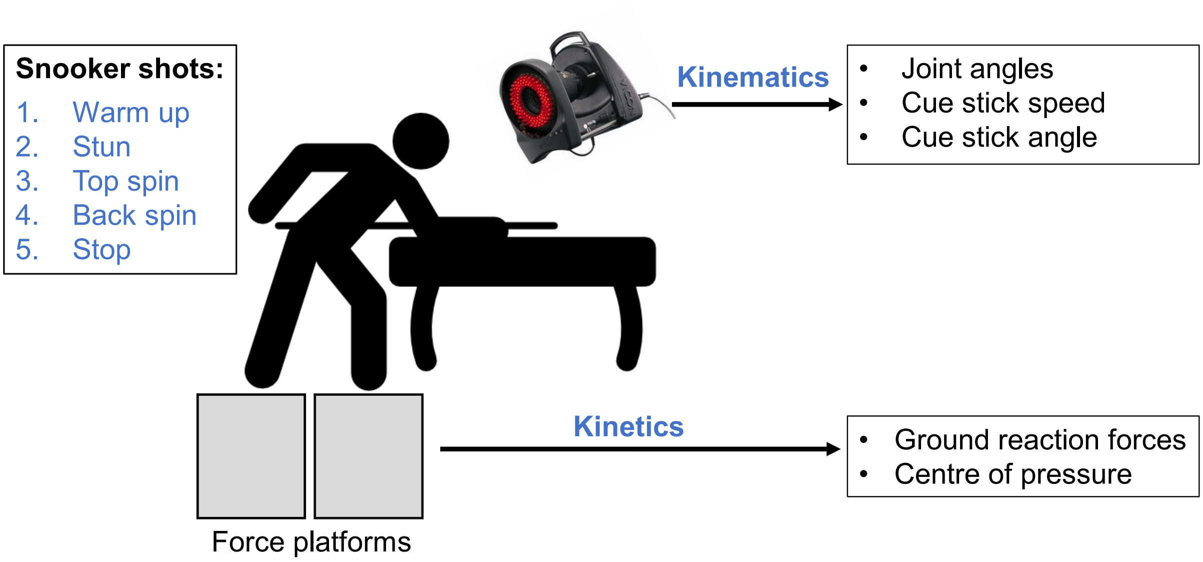

Figure 1. Experiment procedures and variables of interest.

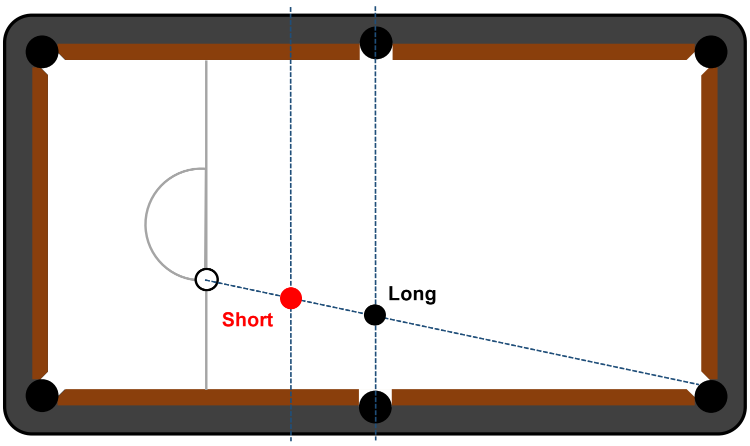

Figure 2. Setup of the cue ball (white) and a near object ball (red) for the short shots and a far object ball (black) for the long shot situations.

Table 1. Protocols of the five selected types of shots in snooker

Tasks	Object ball distance	Description
Warm-up	Short	To conduct a short pot without any spin.
Stun	Short	To pot the near object ball with great power and no spin, such that the cue ball continues to move forward slightly after impact.
Top spin	Short	To pocket the near object ball with top spin such that the cue ball continues going forward after impact.
Back spin	Long	To pot the far object ball with back spin such that the cue ball is drawn back after impact.
Stop	Long	To perform a long pot and park the cue ball immediately after impact.

Data acquisition and analyses

Passive retro-reflective markers were placed on the participant's upper body and his cue stick (one on the cue tip and one on the butt, respectively). Kinematics of the upper body were recorded using the Vicon motion capture system (400 Hz, Vicon MX, Oxford Metrics Ltd., Oxford, UK) for all 15 trials (3 trials × 5 tasks). The participant stood on two force platforms (800 Hz, model 9253A, Kistler Instruments AG, Winterthur, Switzerland), one under each foot, when he executed all shots. Synchronized 3D motion and GRF data were collected throughout.

Raw kinematic data were low-pass filtered using a fourth-order Butterworth filter at the cut-off frequency of 10 Hz according to the results of the residual analysis (Winter, 2009). Upper body joint angles and the marker coordinates were extracted using Visual3D (v6.01.36, C-Motion, Germantown, MD, USA) for each shot. Based on the positions of the cue tip, a stroke can be divided into two main parts namely practice swings and final stroke (Figure 3). In the final stroke, five key moments were identified: (a) start of back swing, (b) end of back swing, (c) start of forward swing, (d) impact, and (e) end of follow through. Based on these key moments, three sub-phases including back swing (a-b), forward swing (c-d), and follow through (d-e) phases were determined. The flexion/extension range of motion (ROM) for wrist and elbow was extracted in the final stroke from back swing to follow through (a-e). The inter-trial variability was calculated as the standard deviation of the 3 trials in each type of shots.

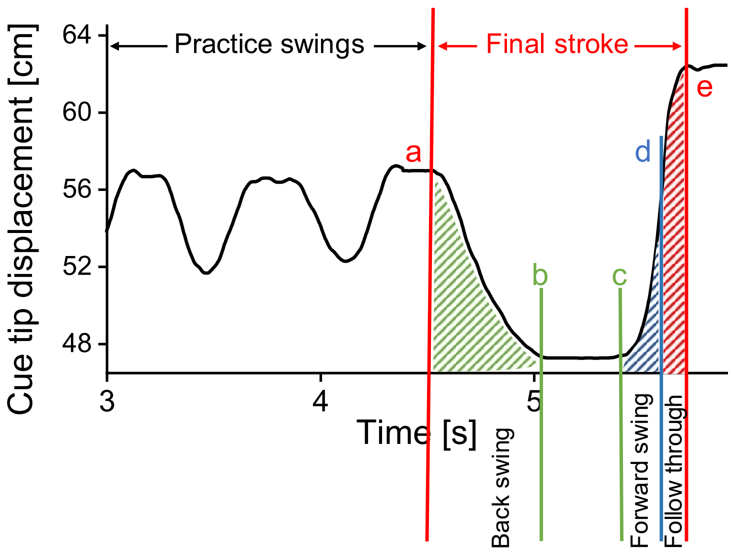

Figure 3. Key moments defined in a stroke of the cueing movement: (a) start of back swing, (b) end of back swing, (c) start of forward swing, (d) impact, and (e) end of follow through.

To examine the cue stick overlap in the practice swings and final stroke, the 3D coordinates of the cue tip and butt were obtained in the last practice swing and at impact. A discrepancy angle, which was defined as the acute angle between the cue stick in the last practice swing (when the cue stick paused before the key moment a) and at impact (key moment d), was computed (Figure 4). A smaller discrepancy angle would indicate a higher level of overlapping, or high similarity between the last practice swing and the final stroke. This method of comparing overlapping of different strokes was similar to that previously used in studying golf swings (Zhang & Shan, 2014).

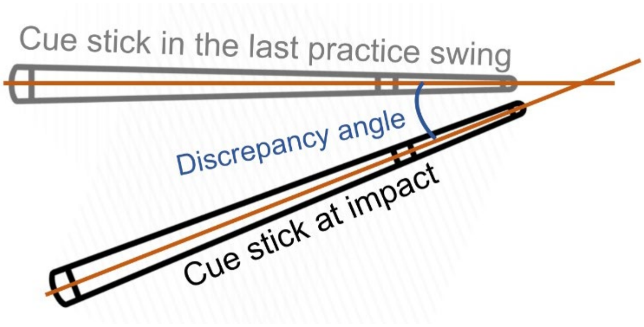

Figure 4. Definition of the discrepancy angle to indicate the overlap in cue stick positions between the last practice swing and the final stroke.

Vertical, mediolateral, and anteroposterior GRF data were low-passed filtered at the cut-off frequency of 50 Hz according to the results of the residual analysis (Winter, 2009). In order to investigate the weight transfer in the mediolateral direction between the two feet during the cueing movement, the $COP_x\%$ (Figure 5) adopted from previous work on golf swings (Ball & Best, 2007b, 2007a) was calculated using the formula (1):

$$COP_x\% = [(F_{z1} * COP_{x1}) + (F_{z2} * COP_{x2})] / (F_{z1} + F_{z2}) \quad (1)$$

where F_{z1} was the vertical force from force platform 1 (right foot), F_{z2} was the vertical force from force platform 2 (left foot), COP_{x1} was the mediolateral COP position from platform 1, and COP_{x2} was the mediolateral COP position from platform 2. This $COP_x\%$ expressed the COP position in the mediolateral direction as a percentage of the distance between the right foot (0 %) and left foot (100 %, Figure 5).

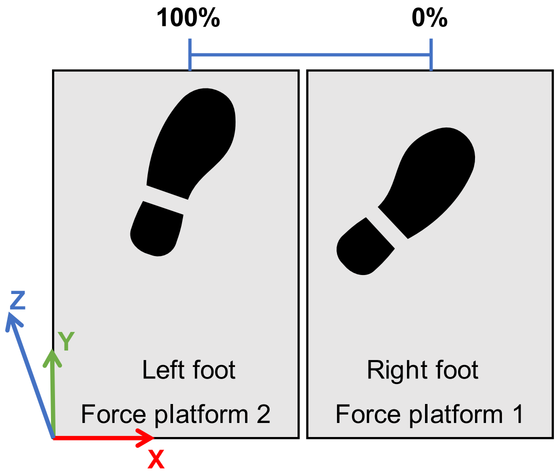

Figure 5. Schematic representation of the player's stance posture on two force platforms and the centre of pressure expressed as the percentage of the distance between two feet (COPx%).

Results

Table 2 shows the success rate (i.e., object ball potted in the pocket) and descriptive kinematic data of the cueing movement in the warm-up, stun, top spin, back spin, and stop shots. The GRF profiles were similar across all shots and all trials and hence, one set of representative data of (back spin shot) were time normalised and displayed in Figure 6.

Table 2. Kinematic data of the cue stick and upper limb joints in five selected shots in snooker.

	Warm-up	Stun	Top spin	Back spin	Stop
Successful rate	1/3	1/3	3/3	1/3	1/3
Discrepancy angle [°]	0.6 (0.1)	0.8 (0.1)	0.9 (0.1)	0.4 (0.1)	0.9 (0.1)
Cue tip speed at impact [m/s]	1.24 (0.04)	2.57 (0.11)	2.58 (0.23)	4.02 (0.04)	2.99 (0.15)
Wrist ROM [°]	26.9 (0.8)	27.9 (0.8)	28.4 (1.0)	25.4 (1.2)	29.7 (1.0)
Elbow ROM [°]	128.3 (1.0)	136.7 (0.2)	137.6 (1.1)	141.2 (2.5)	138.0 (1.2)

Results are shown as mean (standard deviation) of 3 trials for each type of shot.

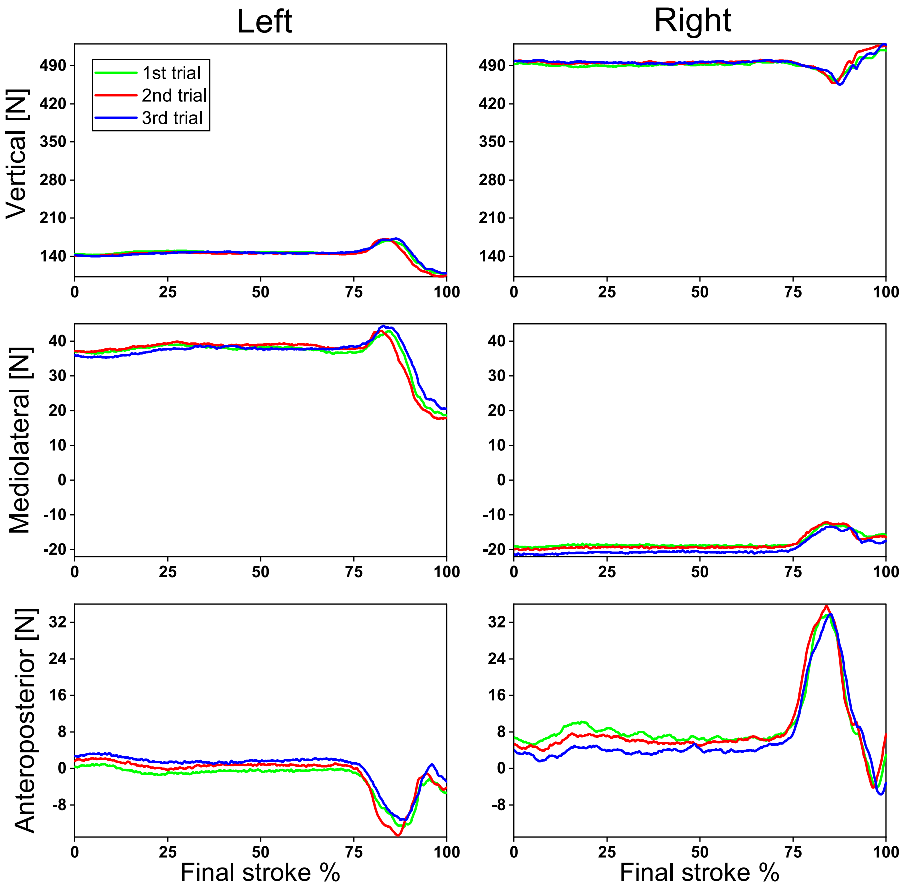

Figure 6. Representative ground reaction forces of 3 trials of the back spin shot (final stroke).

The COP transfer between the two feet at five key moments in the final stroke, expressed as COP_x%, revealed a slight lean towards the left foot (59.6% to 61.7%) throughout the entire cueing movement (Table 3).

Table 3. Transfer of weight (expressed as COP_x%) at five key moments in the final stroke.

	Moment a	Moment b	Moment c	Moment d	Moment e
Warm-up	61.7 (0.6)	61.7 (0.7)	61.6 (0.7)	61.5 (0.8)	61.6 (0.8)
Stun	61.5 (0.6)	61.4 (0.7)	61.3 (0.7)	61.1 (0.8)	61.1 (0.7)
Top spin	60.1 (0.9)	59.9 (0.8)	59.8 (0.8)	59.6 (0.7)	59.8 (0.8)
Back spin	60.6 (0.4)	60.5 (0.4)	60.2 (0.2)	60.3 (0.4)	60.1 (0.4)
Stop	61.0 (0.4)	60.8 (0.4)	60.8 (0.4)	60.6 (0.5)	60.5 (0.4)

Centre of pressure in the mediolateral direction are shown as a percentage of the distance between the right foot (0 %) and left foot (100 %). Moment a: start of back swing; Moment b: end of back swing; Moment c: start of forward swing; Moment d: impact; Moment e: end of follow through.

Discussion

This study presented the biomechanical profile of the cueing movement of snooker, including the kinematics of the cue stick and the upper limb joint as well as the GRF and COP obtained from the force platforms. Regardless of successful or unsuccessful trials, the cueing techniques were similar across the five types of tasks examined (warm-up, stun, top spin, back spin, and stop shots). The inter-trial variability (calculated as the standard deviation of the 3 trials in each type of shots) was relatively small, indicating good consistency among the trials.

<u>*Cue tip speed*</u>

The cue tip speeds at impact differed among the five tests. As expected, the speed was low in the warm-up shots [1.24 (0.04) m/s] during which the participant did not apply much power and focused on pocketing the object ball with a ‘soft’ shot. The highest speed was observed in the back spin shots [4.02 (0.04) m/s] which was a long shot and required the player to apply strong back spin in order to draw back the cue ball upon impact. The cue tip speeds of the various shots determined from the present study were comparable to those reported in previous works. For top spin shots, a previous snooker study on professional snooker players reported the cue tip speed as 2.52 m/s (Song et al., 2018) which was almost identical to our results of 2.58 (0.23) m/s. In their study, the cue tip speed in the back spin was 3.69 m/s which was slightly lower than our result of [4.02 (0.04) m/s]. This discrepancy could be due to different pre-set positions of the object ball and cue ball. As the back spin shot in this present study required a much longer shot compared with the study by Song et al. (2018), a higher cue tip speed was needed to draw the cue ball back after hitting the object ball.

<u>*The ‘pendulum’ movement*</u>

The cueing movement in cue sports has been described as the ‘pendulum movement’ whereby the cue stick is primarily driven by elbow flexion and extension while the other parts of the body are fixed (Leider, 2010; Pan et al., 2021b; Pejcic & Meyer, 1993). Stemming from expert opinions and experience of coaches and elite players, excessive shoulder movements should be avoided during the cueing movement. Results from the present study confirmed the expert opinions that elbow flexion/extension (approximately 130^o ROM) primarily contributed to the cue stick delivery while the wrist flexion/extension contribute much less (less than 30^o ROM). Players are recommended to adopt the technique that largely involves elbow flexion and extension during the cueing movement. In another cue sport of billiards, however, it has been found that the shoulder joint contributed significantly in the cueing movement among beginners with litter or no previous experience (Haar et al., 2020). The present case study investigated only one professional snooker player. It can be expected that the cueing performance of skilled experts differs substantially from less-skilled players as seen in 9-ball (Pan et al., 2021a). Future studies can compare upper limb movements between skilled and less-skilled players across different disciplines of cue sports to clarify the role of shoulder joint in the cueing movement. Based on the current findings, snooker players are advised to limit their shoulder movements during the cueing movement and deliver the cue stick primarily by elbow flexion and extension. For practical applications, snooker players are advised to stabilise their shoulder during the cueing movement and deliver the cue stick primarily via elbow movements.

Overlapping between practice swing and final stroke

In order to examine the similarity of the cue stick positions in practice swings and the final stroke, a discrepancy angle was used to quantify the overlap between the last practice swing and at impact. It is expected that a smaller discrepancy angle would indicate a higher level of overlap and hence higher level of precision. Similar methods were used in a previous study on golf swing which reported a range of discrepancy angles from 1.9° to 6.1° among various phases of successful and failed swings (Zhang & Shan, 2014). In the present study, the professional snooker player exhibited smaller discrepancy angles (less than 1°) across all 15 trials. This reflected that the practice swings, despite without impacting the cue ball, closely resembled the cue stick trajectory of the final stroke which hits the cue ball. Sport scientists and coaches could also adopt the discrepancy angle measurement to evaluate the cue stick delivery in other cue sports such as billiards games. Results from the present studies suggest that players may benefit from executing repeated practice swings in their training to prepare for the final stroke. Cue sport players may reasonably benefit from executing repeated practice swings without making impact with the cue ball in their training.

Stability and weight transfer

Across all five types of snooker shots, the GRF profiles were similar with relatively small changes taking the participant's body weight into consideration (70 kg, 686.7 N). There was very little fluctuation in the GRF magnitude in the final stroke (Figure 6). The steady GRF profiles confirm the anecdotal coaching guidelines that players should keep stable throughout the cueing movement. To understand the weight transfer during 'static' sports such as archery and golf, COP characteristics have been widely used (Ball & Best, 2007a, 2007b; Prieto et al., 1996; Simsek et al., 2019; Zhang & Shan, 2014). In the present study, COP transfer between the two feet at key moments in the final stroke revealed a slight lean towards the left foot (59.6% to 61.7%, Table 3). The COP position was rather stable throughout the cueing movement and there was no clear difference among the five tasks. These findings indicate good stance stability with the COP remained at approximately 60% of the distance between two feet towards the left. As the participant was a professional snooker player, it could be deduced that maintaining stance stability throughout the cueing movement is important for good performance in snooker. Hence, players are advised to maintain a steady stance for all types of shots, with slightly more weight placed on the front leg than the back leg.

Limitations

There are a few limitations to this present study. Firstly, this is a case study on one elite male snooker player and his cueing movements may not represent those of other players. Future studies can use a larger sample size including male and female players at various playing levels. Secondly, only 3 repeated trials were performed for each type of shot. In order to further analyse the inter-trial variability of the cueing movements, future work could administrate 10 to 20 repeated trials. Lastly, there was a lack of measures of the shot performance (e.g., effects of the spins applied) to indicate whether the shot delivered was good or not. potted. One possible way to quantify shot performance is to apply 2D video analysis to track the ball movements on the snooker table and the calculate error distances if the balls from pre-set targets (Pan et al., 2021a).

Conclusion

This study presented the biomechanical profiles of the cueing movement during the practice swings and the final stroke executed by an elite snooker player. The upper limb joint kinematics and force characteristics were similar among the five types of shots examined, namely warm-up shots, stun shots, top spin shots, back spin shots, and stop shots. The small discrepancy angle indicated a high degree of overlapping in the cue stick position between the last practice swing and final stroke. The player maintained high stance stability as reflected by the steady force profiles and minimal weight transfer between the two feet during the cueing movement. Data of the present study can serve as a reference for practitioners and scientists to detect error, enhance training, and improve performance in snooker.

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Competing Interests

The authors have no competing interests to declare.

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